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ANALYSIS OF LASER RANGING AND VLBI OBSERVATIONS  
FOR GEODETIC PURPOSES

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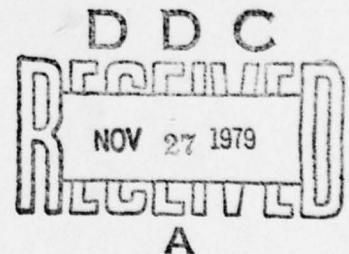
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) From three VLBI experiments carried out in 1977 and 1978, the distances between the antenna at Onsala (Sweden) and radio tele- scopes at Haystack (Massachusetts), Green Bank (West Virginia) and Owens Valley (California) have been determined with formal stan- dard errors as small as a few centimeters and repeatability gener- ally within the 99% confidence interval of the root-sum-squares of these standard errors. Overall it appears that subdecimeter pre- cision has been achieved in these estimates of baseline lengths.		

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Using these data, we have also determined changes in UT1 and in the x and y components of polar motion.

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## I. Coordinates of the Antenna in Onsala, Sweden

Using the data gathered in three VLBI experiments carried out in September 1977, February 1978 and May 1978, we determined the coordinates of the antenna in Onsala, Sweden. (See Table 1 for experiment details.)

The processing of the 1636 interferometric group delays involved three stages. The first consisted of removing group delay ambiguities and deleting the observations for which there was no signal detected (based on a small correlation coefficient and an inconsistency with other observations). The second stage, which required a large amount of time, involved assessing the level of clock and atmosphere modelling required for the data obtained at each of the observing sites. The third stage was the generation of the final solutions in which we obtained estimates of baseline vectors and source coordinates using individual and combined data sets.

In all solutions only the group delays were used to estimate the parameters. The delay rates were used as a means to assess the quality of the group delay solution. This procedure was found to be extremely useful in deciding on the level of clock and atmosphere modelling required for a given data set. For example, if the addition of extra clock and atmosphere parameters improved the postfit residuals of the group delays, while degrading the delay rate residuals, then doubt was cast on the reliability of this solution.

Table 2 gives the values of the distances between the intersection of the azimuth and elevation axes of the Onsala antenna and similar reference points on the other antennas. The results pre-

sented give values from individual and combined solutions. It should be noted that the solutions for which the source positions were not estimated may be biased due to the greater sensitivity to source position errors with Onsala included in the experiments.

The self consistency of these results is gratifying and indicates that the formal standard errors quoted may not be much smaller than the actual errors. The solution in which all the data were combined has been accepted as the most reliable since there is less possibility of clock offsets being absorbed into the Z coordinates of the antenna positions.

From this combined solution, our estimates of the baseline lengths are:

Haystack - Onsala	5,599,714.678 $\pm$ 0.034 m
NRAO - Onsala	6,319,317.765 $\pm$ 0.037 m
OVRO - Onsala	7,914,131.242 $\pm$ 0.040 m

These values are believed to represent the first intercontinental distance determinations with sub-decimeter precision. More experiments must be performed, however, to assess the repeatability of the determinations. To assess accuracy at this level, comparisons would have to be made with determinations based on an independent and, in principle, more accurate technique. Unfortunately, none now exist. The best such technique now available is based on Doppler observations of satellites. Such observations have already been made (W. E. Carter, private communication), and when results become available for these baselines comparisons will be made.

The estimates of the Onsala antenna coordinates (from the combined solution), for the epoch May 17, 1978 are:

$$\text{Onsala } X = 3,370,600.578 \pm 0.055 \text{ m}$$

$$Y = 711,919.035 \pm 0.037 \text{ m}$$

$$Z = 5,349,832.244 \pm 0.093 \text{ m}$$

where the coordinate system is a geocentric, "rigid" earth-fixed system with the Z axis parallel to the mean pole of rotation of 1900-1905 as defined by the International Latitude Service and maintained by the BIH (Bureau International de l'Heure). The X axis is defined to be perpendicular to the Z axis and in the direction of the Greenwich meridian. The Y axis completes the right-handed triad.

Operationally, the location of the origin of the coordinate system and its orientation in inertial space (mean equinox and equator of 1950.0) are defined by the coordinates of the Haystack antenna reference point, which were taken to be:

$$\text{Haystack } X = 1,492,406.691 \text{ m}$$

$$Y = 4,457,267.330 \text{ m}$$

$$Z = 4,296,882.102 \text{ m}$$

and by the standard formulas for UT1, pole positions, sidereal time, nutation and precession at the May 1978 epoch.

In earlier reports\*, we gave values of the Onsala-Haystack and Onsala-NRAO baseline lengths determined from the September 1977 data set. When the earlier determinations are corrected for a change

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\*Quarterly Status reports #1, 2, and 3 for periods: 1 Oct - 31 Dec 1978, 1 Jan - 31 Mar 1978, 1 Apr - 30 June 1978, respectively.



in the speed of light from 299,792.5 km/sec to 299,792.458 km/sec, the differences between these values and the lengths given in this report are -0.5 and -0.6 m. These differences are consistent with the quoted formal standard errors of 0.5 m. The earlier report also gave the coordinates of the Onsala antenna. However, a comparison of these results with the coordinates given in this report is not directly possible due to a difference in the (assumed) coordinates of the Haystack antenna.

The postfit residuals for the experiments involving the North American and Onsala antennas ranged from 0.6 nsec for the May 1978 experiment to 1.7 nsec for the September 1977 experiment. Figure 1 gives a typical postfit residual plot for the May experiment. In all cases the ratio of the a priori estimate of the accuracy of the observations to the a posteriori estimate was of the order of 1.2.

## II. Determination of Polar Motion and UT1 Variations

In the combined solution, where all observations were used simultaneously to estimate baseline vectors and source coordinates, we were also able to estimate polar motion and UT1 for two of the experiment dates. The third experiment date was used as a reference since VLBI can only measure changes in pole position and UT1. All four stations participated in the May 1978 experiment and the BIH values were taken as initial values at this epoch.

Table 3 gives the differences between our values of pole position and UT1 and the BIH values at the other two epochs. Where available, differences deduced from other techniques have also been included in the table.

The agreement between the different techniques is generally good, although in some cases it appears that the formal standard errors may be smaller than the actual errors.

The largest formal standard errors associated with the VLBI determination of pole position are in the y component, which is almost solely determined by the data on baselines involving Onsala. This component has not been well determined because we have only limited data on these baselines in the September and February experiments. However, when more data become available involving Onsala, we can expect to have the y component of pole position as well determined as the x component.

The Lunar Ranging values for UT1 are only preliminary and were obtained from the processing of 2.5 years of data from November 1975 to May 1978. The average formal standard error of the results

was  $\sim 0.5$  milliseconds (ms) of time. However, the residuals still show systematic trends at the 1 ms level which are thought to be due to deficiencies in the mathematical models used for the lunar orbit and rotation (R. W. King and D. S. Robertson, private communication, 1979).

### III. Potential Improvements in the Determination of Source Positions

VLBI observations involving Onsala and the North American antennas, together, potentially yield significant improvements in the accuracy of source positions compared to the accuracy achievable with the North American antennas alone. This conclusion is predominantly a result of the longest baseline length being doubled, and its declination increased from  $6^{\circ}7$  to  $11^{\circ}0$ . These changes afford the improvement in resolution shown in the u-v plane diagram of Figure 2. Also, the  $\sim 70^{\circ}$  difference in the right ascension of the Haystack-Onsala and the Haystack-OVRO baselines means we are able to obtain the right ascension and declination of a source simultaneously. Thus, less time will be required observing a source to obtain good u-v plane coverage.

Unfortunately, the number of observations involving Onsala at this time is still too limited for us to significantly improve the accuracy of the source positions. This condition will be remedied when observations from future experiments are combined with the present data set.



#### IV. Conclusion

This report has shown that subdecimeter precision can be achieved on intercontinental distance measurements using VLBI. It is now necessary to establish if we have achieved the same level of accuracy. Comparison with satellite Doppler observations is one method of assessing accuracy and it is hoped that this comparison will be possible soon. A partial alternative is to carry out further VLBI experiments involving Onsala. In November of this year a Mark III experiment using Onsala is proposed. This should provide a high quality data set which can be compared with the May 1978 solution to obtain some assessment of the repeatability of the baseline-length determination. This does not provide a full check on the accuracy since there may be systematic errors, common to all VLBI experiments, which are currently being absorbed into clock polynomials, station coordinates and source positions.

### Acknowledgements

The observations used in the preparation of this report represent part of the VLBI experiments being carried out by the Goddard Space Flight Center, the Haystack Observatory, the National Geodetic Survey and the Department of Earth and Planetary Sciences at the Massachusetts Institute of Technology. The nature of VLBI experiments requires the combined efforts of numerous people, from an experiment's inception to the final analysis, to ensure its successful completion. This report would not have been possible without the efforts of T. A. Clark from the Goddard Space Flight Center, A. Rogers from the Haystack Observatory, B. O. Rönnäng and O. E. H. Rydbeck of the Onsala Space Observatory, who organized much of the experiment. At the Haystack Observatory, B. Corey carried out much of the work on the Onsala receivers, and A. Whitney, C. Knight, and H. Hinteregger made significant contributions to the organization and running of the experiments. The data bases which contained the observations used to obtain the results

in this report were prepared by J. Ryan and C. Ma of Goddard Space Flight Center, and D. Robertson of the National Geodetic Survey. Without the efforts of these people the results presented here could not have been obtained.

Table 1. Summary of VLBI Experiments Involving Onsala<sup>a</sup>

Dates	21-25 Sept. 77	24-26 Feb. 78	17-19 May 1978
Experiment Duration (hr)	88 <sup>e</sup>	50	45
Participating Stations	Onsala <sup>a</sup> Haystack <sup>b</sup> NRAO <sup>d</sup>	Onsala <sup>a</sup> Haystack <sup>b</sup> OVRO <sup>c</sup>	Onsala <sup>a</sup> Haystack <sup>b</sup> OVRO <sup>c</sup> NRAO <sup>d</sup>
Number of Group Delay Observations	534	272	830
Number of Sources Observed	10	9	10
Declination Range of Sources (deg)	-5.5 to 50.8	2.3 to 50.8	-5.5 to 50.8

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<sup>a</sup> 66-ft diameter antenna at the Onsala Space Observatory, Onsala, Sweden.

<sup>b</sup> 120-ft diameter antenna in Westford, Massachusetts.

<sup>c</sup> 130-ft diameter antenna in Owens Valley, California.

<sup>d</sup> 140-ft diameter antenna in Green Bank, West Virginia.

<sup>e</sup> Onsala only participated for the final 62 hr of the experiment.

Table 2. Comparisons of Baseline Length Estimates from Various Data and Parameter Sets

	OVRO - ONSALA			HAYSTACK - ONSALA			NRAO - ONSALA		
	Length (m)	Formal Standard Error	Diff**	Length (m)	Formal Standard Error	Diff**	Length (m)	Formal Standard Error	Diff**
May 17, 1978	7,914,131.173	± .045	-.069	5,599,714.686	± .028 <sup>§</sup>	.008	6,319,317.776	± .035 <sup>§</sup>	.011
May 17, 1978*	1.082	± .040	-.160	.589	± .022	-.089	.614	± .025	-.151
Feb 24, 1978	1.207	± .169	-.035	.632	± .106	-.046	---		
Sep 24, 1977	---			.509	± .396	-.169	.569	± .340	-.196
Combined	1.242	± .040	0.000	.678	± .034 <sup>§</sup>	0.000	.765	± .037 <sup>§</sup>	0.000
Combined*	0.982	± .044	-.260	.541	± .023	-.137	.573	± .029	-.192
	HAYSTACK - NRAO			HAYSTACK - OVRO			NRAO - OVRO		
	Length (m)	Formal Standard Error	Diff**	Length (m)	Formal Standard Error	Diff**	Length (m)	Formal Standard Error	Diff**
May 17, 1978	845,129.933	± .009 <sup>§</sup>	-.013	3,928,881.673	± .017 <sup>§</sup>	-.010	3,324,244.177	± .016 <sup>§</sup>	-.016
May 17, 1978*	.868	± .009	-.052	.675	± .016	-.008	.194	± .015	.001
Feb 24, 1978				.681	± .054	-.002	---		
Sep 24, 1978	.837	± .071	-.083				---		
Combined	.920	± .012 <sup>§</sup>	.000	.683	± .021 <sup>§</sup>	.000	.193	± .020 <sup>§</sup>	.000
Combined*	.879	± .011	-.046	.645	± .019	-.038	.181	± .018	-.012

\* Source positions not estimated. These solutions may be biased due to the sensitivity of the experiments involving Onsala to source position errors.

\*\* Difference from combined solution.

§ Due to software limitations, it was necessary to reduce the clock and atmosphere models in the combined solution resulting in the formal standard errors in this solution being greater than the May solution alone. As stated in the text, the combined solution was taken as the most reliable since it is less susceptible to clock offsets being absorbed into the Z coordinate.



Table 3. Pole Position and UT1 Differences Between Estimates from BIH, VLBI and Other Techniques

	<u>VLBI</u>	<u>IPMS</u> <sup>a</sup>	<u>Doppler</u> <sup>b</sup>	<u>LLR</u> <sup>c</sup>
24 Feb. 1978				
x component <sup>d</sup> (m arcsec)	-33.6 ± 2.2	-19	-60 ± 6	--
y component <sup>d</sup> (m arcsec)	15.1 ± 7.0	13	- 6 ± 6	--
UT1 <sup>d</sup> (m time sec)	- 3.0 ± 0.1	-	-	-3.2 ± 0.4
24 Sep 1978				
x component <sup>d</sup> (m arcsec)	-80.3 ± 7.7	-62	-53 ± 6	-
y component <sup>d</sup> (m arcsec)	- 4.9 ± 9.1	-18	-20 ± 6	-
UT1 <sup>d</sup> (m time sec)	- 1.0 ± 0.3	-	-	-1.6 ± 0.4

<sup>a</sup> International Polar Motion Service, values obtained by interpolation of 0.05 year smoothed values compiled by D. S. Robertson (NGS) from the Monthly Notices of the IPMS. No formal standard errors are given.

<sup>b</sup> Naval Weapons Laboratory and Defense Mapping Agency reductions of Doppler tracking of transit satellites. Values interpolated from 0.05 year smoothed values given in the BIH Annual Report for 1978, p. D-13. All values are preliminary.

<sup>c</sup> Lunar Laser Ranging preliminary values obtained from D. S. Robertson and R. W. King (private communications).

<sup>d</sup> 17 May 1978 taken as reference point; all values initialized to agree with BIH.

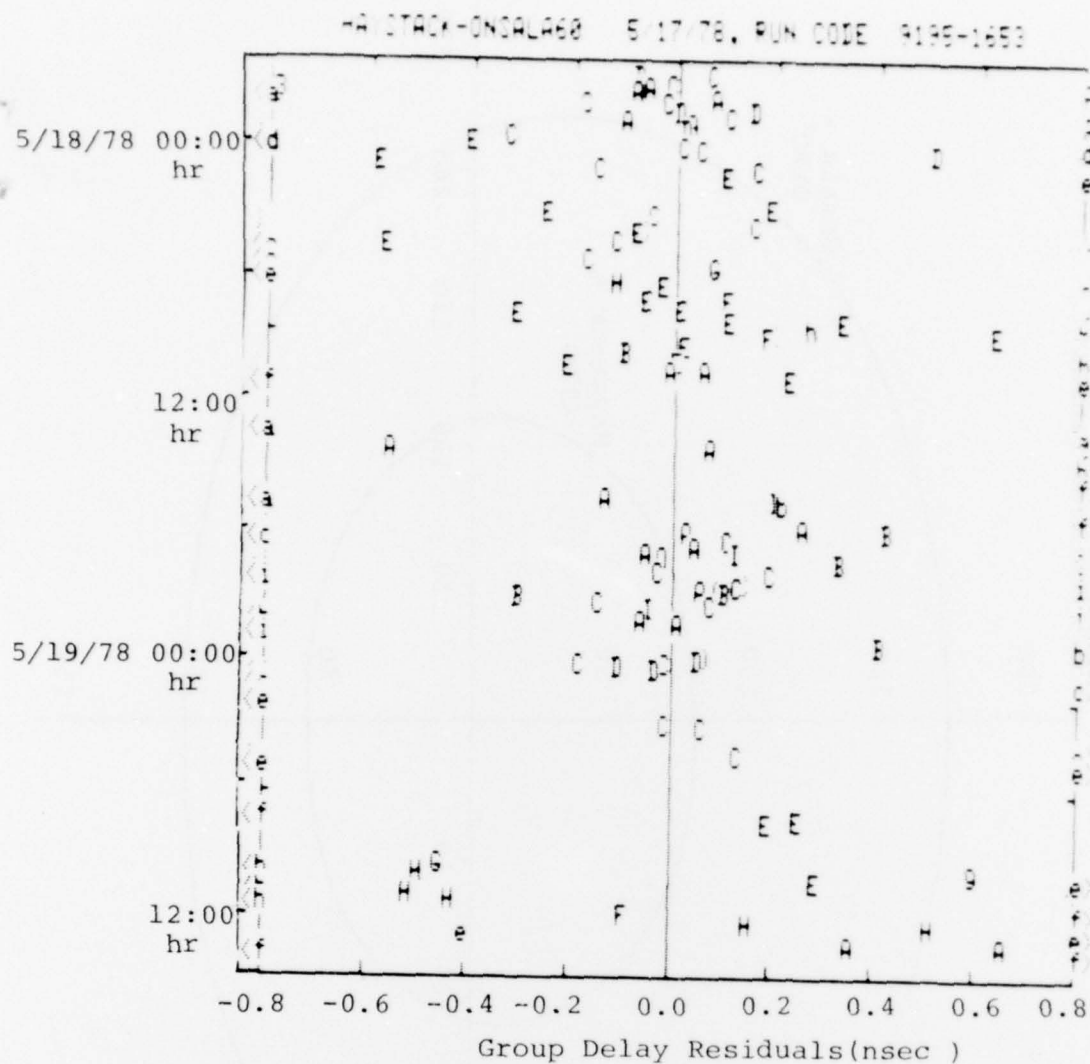


Figure 1. Postfit residuals for Haystack-Onsala baseline from the 17 May 1978 data set.

The letters refer to observed sources

A= NRA0150, B= 3C84, C= 4C3925, D= 3C273B, E= 3C345, F= VRO422201, G= 2134+00, H= 3C454.3

Lowercase letters denote deleted points. (Achieved by giving the observation a standard error of 1 sec.)

Figure 2. Comparison of U-V plane coverage for Haystack-OVRO and  
Onsala-OVRO Baselines.

